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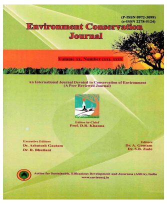

Productivity and nitrogen use efficiency of rice under conventional and organic nutrition

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ABSTRACT

The current study demonstrates the influence of conventional and organic nutrient management practices on nitrogen use efficiency, growth, yield, and physiological and biochemical parameters in four rice varieties, namely, Jaiva, Ezhome 2, Jyothi and Uma. Growth parameters, grain yield per hill, and physiological and biochemical parameters were higher under conventional management for all rice varieties. Although the nitrogen use efficiency of each variety varied significantly with nutrient management practices, the variation was least in Jaiva (23.8%), which is the organic rice variety released by Kerala Agricultural University. The rice varieties Jaiva and Ezhome 2 showed consistency in the grain weight per panicle under both conventional (Jaiva-4.57 g, Ezhome 2- 5.86 g) and organic (Jaiva, 4.24 g, Ezhome 2, 4.54 g) management. The soil nitrogen content at the tillering stage (0.66^{**}) showed a significantly higher positive correlation with nitrogen use efficiency under organic management. The results of the study provide a better understanding of factors that can lead to a sustained yield in organic rice production in terms of nitrogen use efficiency.

Introduction

The agriculture sector is estimated to be responsible for 60 percent of the projected increase in N pollution by 2050, which is expected to be 150 percent more than that in 2010 (Martinez-Dalmau *et al.*, 2021). Rice (*Oryza sativa* L.) is one of the staple cereal food crops for approximately half of the global population. Because of the lower nitrogen use efficiency, rice cultivation has become a fertilizer-intensive process, leading to many environmental implications (Chivenge *et al.,* 2021). Hence, organic farming is quickly gaining popularity as a potential way to ensure ecological

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sustainability and produce healthier food. Despite this, organic farming of rice has a number of limitations, such as decreased yield, lack of suitable varieties, N stress at critical growth stages, shortage of quickly mineralizable organic additions, and crop-weed competition that make it difficult to achieve the potential output (Hazra *et al*., 2016).
Nitrogen (N) is a significant element that plays a vital role in the growth and yield of rice. Suboptimal nutrient input (N in particular) is one of the many yield-limiting factors that causes a noticeable yield difference between conventional and organic production methods for rice (Wild *et al*., 2011; Hazra *et al*., 2014). A better understanding of the nitrogen use efficiency (NUE) of rice genotypes may be helpful in the increased adoption of organic rice farming with a lower yield gap.The current study compared the influence of conventional and organic nutrient management practices on the nitrogen use efficiency of four rice varieties, two popular rice varieties (Uma and Jyothi) in Kerala and two varieties (Jaiva and Ezhome 2) that are recommended for organic cultivation (Vanaja *et al*., 2013; Manjunatha *et al.,* 2016., Vanaja *et al.,* 2017).

Material and Methods

Plant Materials

Rice varieties of *Oryza sativa* ssp. *indica,* namely, Jaiva, Jyothi, Ezhome 2 and Uma, were used for the study. Breeder seeds of rice varieties Jaiva and Ezhome 2 were procured from the Regional Agricultural Research Station, Pilicode, Kerala, India. The breeder seeds of rice varieties Uma and Jyothi were collected from Rice Research Station, Moncompu, Kerala, India and Regional Agricultural Research Station, Pattambi, Kerala, India, respectively.

Experimental Conditions

The experiment was conducted at the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India, during the first crop season (June to October) of 2021 in open conditions. The weather data on maximum and minimum temperature (°C), relative humidity (%), total rainfall (mm) and bright sunshine hours (h) were collected from the class B Agromet observatory of the Department of Agricultural Meteorology, College of Agriculture, Vellayani (Supplementary data). Seeds of rice varieties were weighed individually and treated for 12 to 16 hours with *Pseudomonas fluorescens* at 10 g/liter of water before sowing (PoP KAU*,* 2016). Rice varieties were grown under conventional, organic and controlled management conditions. Germinated rice seeds were sown in pots (3 plants per pot) arranged in a completely randomized design with five replicates. The soil used for the experiment (10 kg of soil per pot) was well-pulverized sandy clay loam, acidic in reaction (pH-5), high in organic carbon (1.78%), medium in available nitrogen (313.6 kg/ha), high in available phosphorus (27.52 kg/ha) and medium in available potassium (186.35 kg/ha). Lime was applied at a rate of 600 kg/ha in two split doses., i.e., the first dose (1.75 g per pot) as basal dressing and the second dose (1.25 g per pot) as top dressing at one month after sowing. Lime application and fertilizer application were separated by a week. Straight fertilizers were used in conventional management, and in the case of organic management, nutrients were supplied as farm yard manure (0.5%) and neem cake (4%) on an N equivalent basis (PoP (Organic) KAU*,* 2017). In conventional management, nutrient recommendations of 70:35:35 kg NPK/ha and 90:45:45 kg NPK/ha were followed for short- and medium-duration varieties, respectively (PoP KAU*,* 2016). The control was maintained without manures and fertilizers.

Measurement of traits associated with NUE

Growth, yield and physiological attributes were systematically recorded in different growth stages under conventional, organic and control conditions.
Growth attributes such as plant height (cm) and the number of tillers were recorded during the tillering stage, panicle initiation stage and grain filling stage of the crop, and root characteristics such as root biomass (g) and root depth (cm) were also measured. Yield attributes include grain yield per hill (g), number of productive tillers per hill, length of the panicle (cm), grain weight per panicle (g), thousand grain weight (g) and straw yield per hill (g) (*Standard evaluation system of rice*, 2002).
Physiological parameters such as photosynthetic rate (μmol $CO_2/m^2/s$), transpiration rate (mmol $H_2O/m^2/s$), water use efficiency (mmol CO_2/mol H_2O), and stomatal conductance (mmol/m^2/s) were measured at 45 and 60 days after sowing using a portable photosynthetic system (CIRCAS-3 SW), and biochemical analyses such as total soluble protein content (PC), total free amino acids (AA)

and reducing sugar (RS) content were estimated from leaf tissue after 60 days of sowing. Total soluble protein content (mg/g) was estimated by the Bradford protein-dye binding assay (Bradford, 1976), and total free amino acids (mg/g) were estimated by the ninhydrin method (Yemm *et al.*, 1955). The dinitro salicylic acid method was used to estimate reducing sugar (mg/g) (Manickam and Sadasivam, 1996).

Soil nitrogen analysis

Soil samples were collected at the tillering, panicle initiation and grain filling stages of the crop, and soil N was analyzed by the micro-Kjeldahl method (Jackson, 1973).

Nitrogen use efficiency (NUE)

The agronomic nitrogen use efficiency of different varieties under organic and conventional management was calculated from the observations taken during the experiment. The formula for calculating agronomic NUE is below (Dobermann and Achim, 2005).

Agronomic NUE= $(Y_N - Y_0)/F_N$

F_N - Amount of (fertilizer) N applied (kg/ha), Y_N - Crop yield with applied N (kg/ha), Y_0 - Crop yield (kg/ha) in a control treatment with no N

Statistical analysis

Analysis of variance (ANOVA) was performed for all traits using $GRAPES_{1.0.0}$ (General R-shiny-based Analysis Platform Empowered by Statistics) developed by the Department of Agricultural Statistics, College of Agriculture, Vellayani, Kerala Agricultural University, Kerala, India based on R software (Gopinath *et al.*, 2020). The difference between treatments was separated using least significant difference (LSD) tests at 5% probability. Correlation coefficient analysis (Pearson's linear correlation) using R software was performed between NUE and other shortlisted parameters, and their significance was tested.

Results and Discussion

Growth parameters

The effects of nutrient management on plant height and the number of tillers per hill at all stages of the crop are presented in Table 1. Irrespective of varieties, plant height and number of tillers per hill varied significantly in response to treatments. In the variety Jaiva, plant height at the tillering stage (84.24 cm) under organic management was statistically similar to that under conventional management (87.38 cm).The exception was seen in the number of tillers per hill for the varieties Uma and Ezhome 2 at the panicle initiation stage (21.14 and 14; 20 and 13.2), in which both conventional and organic treatments were statistically similar. A previous study by Ismael *et al.* (2021) depicted that N fertilizer urea in combination with manure improved plant height and the number of tillers and suggested that a combination of chemical fertilizers along with organic manure showed more efficient production than the sole application of fertilizers. In Nepal, a study conducted by Budhathoki *et al.* (2018) compared N fertilizer applications in rice, namely, farmers' fertilizer practices and nutrient expert practices. It was found that the nutrient expert's advice on the application of N significantly increased the plant height of rice. In a study conducted in China, when organic manure coupled with inorganic fertilizer was used in rice, it was found that 70% of chemical fertilizers along with poultry manure showed better growth characteristics, including rice root morphology (Iqbal *et al.,* 2019).Root biomass and root depth were significantly different in all varieties, and maximum root biomass and root depth were recorded in conventional management except in the case of variety Jyothi, in which maximum root biomass and root depth were seen in organic management (Table 2). The root depth of variety Uma under conventional and organic management was found to be statistically similar. Genotypes with higher NUE adapt themselves to the availability of soil N and enhance absorption by regulating different transporter genes encoding NO_3^- and NH_4^+ uptake, which also leads to variation in root morphology (Garnett *et al.*, 2009). The plant will adapt by modifying root length density and root hair growth to enable better N transport and metabolism. These variations in root morphology vary within the species and are essential for acquiring nutrients with low mobility (NO_3^- and NH_4^+) in the soil (Otoole and Bland, 1987). This can be a reason for the variation in root morphology among rice varieties. In contrast to this finding, Fan *et al.* (2010) showed that increased N application increased root length and root biomass. However, Wang *et al.* (2005) noted that high N availability reduces root biomass.

Table 1: Effect of nutrient management on plant height (cm), number of tillers and soil N (kg/ha)

Plant height (cm)												
Treatments	Tillering stage				Panicle initiation stage				Grain filling stage			
	J	E	U	Jy	J	E	U	Jy	J	E	U	Jy
Conventional	87.38	117.42	81.40	68.00	129.18	156.9	104.18	104.64	132.56	136.54	105.48	92.18
Organic	84.24	103.66	66.40	59.30	119.20	113.6	83.70	88.44	114.08	131.70	87.78	84.02
Control	73.44	98.56	60.38	49.22	96.16	131.63	82.20	87.38	84.24	126.04	82.02	59.20
SEm(±)	1.64	3.25	1.65	0.96	1.90	4.43	1.27	1.80	1.16	0.74	0.83	0.68
CD (0.05)	5.06	10.00	5.07	2.96	5.85	13.66	3.92	5.53	3.56	2.29	2.57	2.11
Number of tillers												
Treatments	Tillering stage				Panicle initiation stage				Grain filling stage			
	J	E	U	Jy	J	E	U	Jy	J	E	U	Jy
Conventional	42.2	30.4	33	21.0	21.4	14.0	21.4	21.4	20.0	14.4	21.0	19.2
Organic	22	19.4	28	15.2	15.2	13.2	20.0	13.4	15.2	13.0	18.0	17.2
Control	14.2	11.0	17	11.0	11.4	9.0	14.0	12.0	12.4	9.2	14.0	13.2
SEm(±)	1.03	0.78	0.75	1.12	0.70	0.67	0.89	0.90	0.66	0.58	0.71	1.97
CD (0.05)	3.17	2.40	2.32	3.44	2.15	2.06	2.73	2.77	2.03	1.78	2.18	0.64
Soil N (kg ha^{-1})												
Treatments	Tillering stage				Panicle initiation stage				Grain filling stage			
	J	E	U	Jy	J	E	U	Jy	J	E	U	Jy
Conventional	255.72	338.45	213.15	250.36	225.52	300.66	288.93	225.91	388.53	363.31	328.08	275.59
Organic	351.23	255.39	250.53	250.48	250.85	351.24	250.88	263.18	391.58	288.30	288.30	326.08
Control	213.25	263.17	300.52	225.47	263.38	238.20	242.32	240.47	246.95	250.85	250.76	255.70
SEm(±)	2.43	1.85	3.15	2.12	4.2	2.36	2.89	3.76	4.98	2.40	3.34	2.87
CD (0.05)	7.49	5.69	9.69	6.52	12.94	7.28	8.93	11.6	15.35	7.40	10.30	8.83

*** J-Jaiva E-Ezhome 2 U- Uma Jy- Jyothi**

Table 2: Effect of nutrient management on root biomass (g) and root depth (cm)

Treatments	Jaiva		Ezhome 2		Uma		Jyothi	
	RB	RD	RB	RD	RB	RD	RB	RD
Conventional	72.32	43.3	103.32	39.70	38.62	35.34	15.52	41.80
Organic	29.52	34.0	65.60	29.52	28.64	33.10	18.60	46.34
Control	15.22	36.3	15.80	47.54	15.10	33.44	4.57	26.52
SEm(±)	0.43	0.28	5.40	0.45	0.45	0.42	0.65	0.32
CD (0.05)	1.34	0.87	16.63	1.4	1.39	1.30	1.99	0.97

***RB- Root biomass RD- Root depth**

Yield attributes

The productive tillers per hill were significantly higher under conventional management for varieties Jaiva (17) and Ezhome 2 (14.4) (Table 3). However, in varieties Uma and Jyothi, it was statistically at par with organic management. Conventional management was found to be significantly superior in the length of the panicle. The rice varieties Jyothi (3.53 g) and Uma (2.82 g) under conventional management showed maximum grain weight per panicle, and Jaiva (4.57 g) and Ezhome 2 (5.86 g) under conventional management were significantly similar to those under organic management (4.24 g and 4.54 g, respectively). Conventional management in all varieties resulted in a considerably higher number of filled grains per panicle during the experiment. The thousand-grainweight of all rice varieties, except Jyothi, was significantly higher under conventional management (Table 3). In variety Jyothi, this parameter was statistically at par under both conventional (30 g) and organic management (30.24 g). Conventional management showed maximum grain yield and straw yield in all varieties. Previous studies comparing conventional and organic management conditions also showed similar results. A significant yield gap was seen between conventional and organic management (Ponisio *et al.*, 2015). This yield gap varies in accordance with the crop and was found to be higher for cereals (Seufert *et al.*, 2012). Plants can absorb nitrogen in the form of urea faster than

Table 3: Effect of nutrient management on yield attributes

Varieties	Treatments	Number of Productive tillers per hill	Length of the panicle (cm)	Grain weight per panicle (g)	Filled grains per panicle	Thousand grain weight (g)	Grain yield per hill (g)	Straw yield per hill (g)
Jaiva	Conventional	17.0	33.14	4.57	194.6	22.24	78.10	39.08
	Organic	14.2	28.60	4.24	135.2	19.27	61.04	24.94
	Control	8.4	20.70	1.60	84.0	18.92	13.80	20.02
	SEm(±)	0.41	0.67	0.24	5.91	0.45	3.43	0.69
	CD(0.05)	1.26	2.06	0.74	18.22	1.37	10.56	2.12
Ezhome 2	Conventional	14.4	31.52	5.86	157.0	31.40	86.30	47.08
	Organic	12.4	29.82	4.54	174.0	27.44	63.11	22.98
	Control	9.2	26.40	4.97	135.2	26.52	42.10	10.36
	SEm(±)	0.54	0.37	0.09	2.85	0.22	1.97	0.46
	CD(0.05)	1.65	1.14	0.28	8.78	0.68	6.071	1.43
Uma	Conventional	18.4	24.54	2.82	147.2	24.80	53.03	36.32
	Organic	16.4	22.72	1.90	112.2	22.92	27.76	24.72
	Control	12.2	20.64	1.70	67.0	20.60	23.56	16.12
	SEm(±)	0.79	0.33	0.10	3.97	0.27	2.09	0.34
	CD(0.05)	2.43	1.02	0.31	12.22	0.85	6.425	1.04
Jyothi	Conventional	17.0	25.34	3.53	95.2	30.00	56.01	24.40
	Organic	16.0	22.72	2.61	75.4	30.24	40.21	17.04
	Control	12.4	22.06	2.44	48.2	28.60	27.82	7.60
	SEm(±)	0.67	0.37	0.15	4.13	0.21	1.12	0.35
	CD(0.05)	2.08	1.14	0.47	12.71	0.65	3.432	1.07

Table 4: Effect of nutrient management on physiological parameters

Photosynthetic rate (µmol $CO_2/m^2/s$)								
Treatments	Vegetative stage				Reproductive stage			
	J	E	U	Jy	J	E	U	Jy
Conventional	25.53	26.63	29.67	29.59	44.27	45.80	31.35	41.37
Organic	24.58	22.82	25.51	27.01	33.24	30.45	28.54	29.52
Control	25.46	21.82	25.28	25.38	29.05	29.58	29.42	28.11
SEm (±)	0.67	1.18	0.62	0.82	0.11	0.19	0.28	0.07
CD (0.05)	NS	3.63	1.91	2.52	0.34	0.60	0.86	0.22
Transpiration rate (m mole $H_2O/m^2/s$)								
Treatments	Vegetative stage				Reproductive stage			
	J	E	U	Jy	J	E	U	Jy
Conventional	3.78	3.17	3.72	2.65	8.37	13.00	12.91	13.29
Organic	3.48	2.79	3.12	3.58	12.84	12.06	17.90	19.44
Control	1.40	1.35	2.42	2.61	15.63	14.58	17.26	17.98
SEm (±)	0.28	0.11	0.19	0.21	0.36	0.15	0.19	0.2
CD (0.05)	0.88	0.35	0.61	0.67	1.09	0.47	0.61	0.62
Stomatal conductance (mmol/m^2/s)								
Treatments	Vegetative stage				Reproductive stage			
	J	E	U	Jy	J	E	U	Jy
Conventional	214.00	167.20	213.20	121.40	365.8	536.0	385.2	384.0
Organic	177.40	149.20	134.60	181.60	354.2	285.8	635.6	593.8
Control	71.60	62.80	236.20	172.60	455.4	376.2	427.6	655.8
SEm (±)	13.41	8.77	7.88	13.18	3.68	2.83	6.45	70.82
CD (0.05)	41.32	27.01	24.27	40.61	11.33	8.72	2.09	218.21
Water use efficiency (mmol CO_2/mol H_2O)								
Treatments	Vegetative stage				Reproductive stage			
	J	E	U	Jy	J	E	U	Jy
Conventional	13.91	7.70	8.38	15.07	5.44	3.36	3.19	1.93
Organic	7.06	7.97	8.19	10.57	2.43	2.74	2.73	1.55
Control	18.03	18.62	8.33	11.60	1.76	2.03	3.19	1.52
SEm (±)	2.20	1.03	0.84	1.8	0.01	0.03	0.01	0.01
CD (0.05)	6.76	3.18	NS	NS	0.04	0.08	0.03	0.03

organic manures (Bana *et al*., 2022; Xin *et al.,* 2022), and the easily available nitrogen content in organic fertilizers was found to be lower than that in inorganic fertilizers (Ruan *et al*., 2023). This may be a reason for the higher yield in conventional management in comparison to organic nutrient management. Some researchers suggest that the combination of organic and inorganic fertilization will help increase rice productivity and can be used for sustaining soil fertility (Haque *et al.,* 2019). N is an important element in controlling the number of ineffective tillers of *indica* rice and increasing the number of effective panicles (Budhar and Palaniappan, 1996). A previous study by Vanaja *et al.* (2013) compared conventional and organic nutrient management of rice varieties Jyothi, Uma, Athira and Culture MK 157 and found that conventional management produced more grain and straw yields than organic nutrient management. A similar yield reduction (20 to 30%) was also seen under the organic nutrient management of other crop varieties (Seufert *et al*., 2012). This signifies the development of nitrogen use-efficient varieties for better performance under organic nutrient conditions.

Physiological parameters

In the vegetative stage, the rice genotypes Ezhome 2, Uma and Jyothi showed significantly higher photosynthetic rates (26.63 µmol CO2/m2/s, 29.67 µmol CO2/m2/s, 29.59 µmol CO2/m2/s, respectively) under conventional management (Table 4). The different nutrient management systems did not significantly affect the photosynthetic rate of the variety Jaiva. However, in the reproductive stage, all rice genotypes showed a significantly high photosynthetic rate under conventional management. In the vegetative stage, the transpiration rates of varieties Jaiva and Uma were statistically similar. The rice variety Jyothi exhibited a higher transpiration rate under organic management (3.58 mmole $H_2O/m^2/s$) than under conventional management (2.65 mmole $H_2O/m^2/s$). A similar trend was also observed in the reproductive stage. The stomatal conductance of the variety Jyothi at the vegetative (181.6 $mmol/m^2/s$) and reproductive (655.8 $mmol/m^2/s$) stages was higher in the organic management and control treatments than in the conventional management treatment. In this study, the rice varieties Uma and Jyothi did not show any significant difference in water use efficiency in their vegetative stage under different nutrient management practices. However, all rice varieties progressing through the reproductive stage showed a significant increase in water use efficiency under conventional management. Previous studies report the strong relation of photosynthesis to N supply and uptake. The photosynthetic rate, transpiration and stomatal conductance were found to be higher in the N treatment than in the control (Iqbal *et al*., 2019). Inorganic fertilizers helped to increase the photosynthetic rate at the early stages of crop growth, and organic fertilizers helped enhance photosynthetic ability throughout the growing period (Yang *et al*., 2015). Previous studies also reported that modification of stomatal conductance led to better nutrient absorption and higher yield (Kingori *et al*., 2016). It was found that ammonium fertilizer responded more to plants' photosynthetic machinery than N's nitrate form. These studies strongly prove that the state of N affects the photosynthetic machinery of plants (Torralbo *et al*., 2019). Various forms of N fertilizer may differentially regulate stomatal conductance.

Biochemical parameters

The protein content of the rice varieties Jaiva, Uma and Jyothi was significantly higher under conventional management, except in the case of Ezhome 2 (Table 5). The rice varieties Jaiva and Uma showed significantly higher amino acid contents under conventional management than under organic management, whereas the amino acid content of Jyothi was statistically similar. Reducing sugar was significantly higher under conventional management for varieties Jaiva, Ezhome and Uma. In Jyothi, the nutrient management practices did notshow any significant effect on reducing sugar content. Various studies showed that the protein content in the leaf varied according to the form of nutrients applied, and ammonium- and nitrate-fertilized plants were found to have higher leaf protein contents (Torralbo *et al*., 2019). These results support higher protein content in conventional than organic nutrient management. The form of N available in the soil, N uptake efficiency, photosynthesis, etc., are critical factors affecting the assimilation of amino acids in plants. These compounds vary according to the genotype of the crop because of the difference in the expression of genes encoding key enzymes required

Table 5: Effect of nutrient management on total soluble protein content, total free amino acids and reducing sugar content

Treatments	Protein content (mg/g)				Amino acids (mg/g)				Reducing sugar (mg/g)			
	J	E	U	Jy	J	E	U	Jy	J	E	U	Jy
Conventional	1.57	1.06	1.03	1.27	0.74	0.62	0.64	0.57	9.33	9.04	9.24	8.77
Organic	1.22	1.20	1.17	0.93	0.53	0.60	0.53	0.53	9.15	8.90	8.64	8.77
Control	0.95	1.03	0.92	0.78	0.50	0.52	0.52	0.47	8.96	8.59	8.59	8.73
SEm(±)	0.02	0.04	0.02	0.03	0.02	0.03	0.02	0.01	0.04	0.02	0.05	0.04
CD(0.05)	0.07	0.12	0.07	0.08	0.07	NS	0.07	0.04	0.12	0.06	0.17	NS

for amino acid synthesis (Decouard *et al.,* 2022).

Soil nitrogen analysis

At the tillering stage, higher soil N was found in Jaiva under organic management (351.23 kg/ha) (Table 1). The soil N status at the panicle initiation stage was significantly high under organic management for varieties Jaiva (250.85 kg/ha), Ezhome 2 (351.24 kg/ha) and Jyothi (263.18 kg/ha). At the grain filling stage of the crop, soil N was significantly higher in organic management for Jyothi (326.08 kg/ha) than in conventional management. Significant variation in soil N was observed based on the genotype. N uptake and N availability in the soil vary depending on the genetic variability of the crop (Han *et al*., 2015). This report substantiates the difference in soil N in different varieties even though the applied fertilizer dosage was the same under conventional and organic conditions. The long mineralization nature of organic manures compared with that of conventional management may be a reason for the high soil N in organic conditions. Previous studies have shown that the duration and availability of mineral nitrogen vary for manures and inorganic fertilizers. Mineralization of organic manures such as vermicompost and neem cake is slower than that of urea. Therefore, organic manures are more effective for providing a nitrogen supply for an extended period (Velmurugan and Swarnam, 2013). Inorganic fertilizers are readily available to the plant and quickly depleted from the soil. However, with organic manures, the initial quick release phase lasted for 10 to 20 days, followed by a sluggish phase for 30 to 40 days, maximal mineralization for 55 to 90 days, and then a decreased period for 120 days. Hence, organic manures ensure the long-term availability of nutrients in the soil, and the stage of application of organic fertilizers is important for better yield. It was also reported that if nutrients were readily available to the plant, plant absorption would be enhanced (Inthavong *et al.,* 2011).

Nitrogen use efficiency (NUE)

All the varieties under conventional management showed higher NUE than those under organic management conditions (Figure 1). The maximum NUE was seen in Jyothi (0.28) under conventional management. Variation in nitrogen use efficiency under organic and conventional management was found to be lower in the variety Jaiva (23.8%). Rice varieties Ezhome 2, Jyothi, and Uma showed differences of 53.3, 57.1 and 80 percent, respectively. As the first organic rice variety of Kerala Agricultural University (KAU), the performance of Jaiva was studied earlier and found to be superior among 65 genotypes under organic management (Manjunatha *et al*., 2016). A previous report also showed that rice's agronomic NUE and N recovery efficiency were significantly lower under organic production (Huang *et al*., 2016). Varieties differ in terms of uptake and usage of the N fertilizer that is available. Huang *et al*. (2016) recommended that variety selection for organic farming might be made under low-input organic conditions to generate more N-efficient crops.

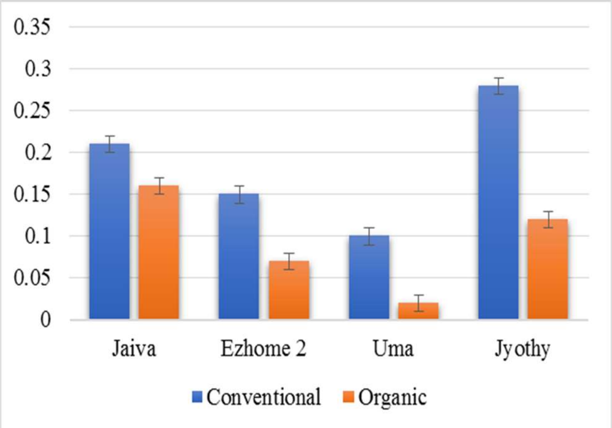

Figure 1: Effect of nutrient management on nitrogen use efficiency

Correlation analysis

The correlation coefficients among NUE and parameters such as grain yield, morphological parameters, soil N status, and some of the physiological and biochemical parameters under conventional and organic management conditions are shown in Figures 2a and 2b, respectively. The perusal of the data (Figure 2a) showed that under conventional management, root depth (0.81***), the photosynthetic rate at the panicle initiation stage (0.47*) and protein content (0.58**) had a significant positive correlation with NUE. Under organic management (Figure 2b), the soil nitrogen content at the tillering stage (0.66**), photosynthetic rate at the panicle initiation stage (0.74***), transpiration rate (0.49*), and stomatal conductance at the vegetative stage (0.74***) showed a significant positive correlation with NUE. Correlation studies in relation to NUE are very few. Some previous studies showed that grain yield per plant had a positive and significant correlation with panicle number per plant, full grain number per panicle, and thousand-grain weight and showed a negative correlation as the growth stage progressed, especially with thousand-grain weight (Saleh *et al.*, 2020). The leaf area index, nitrogen uptake, agronomic efficiency, and recovery efficiency were also positively correlated with grain yield. In contrast, nitrogen uptake and leaf area index showed a significant negative correlation with internal N use efficiency (Chen *et al.*, 2022). Ahmed *et al.* (2016) found a significant interaction between the N rate and grain yield of crops.

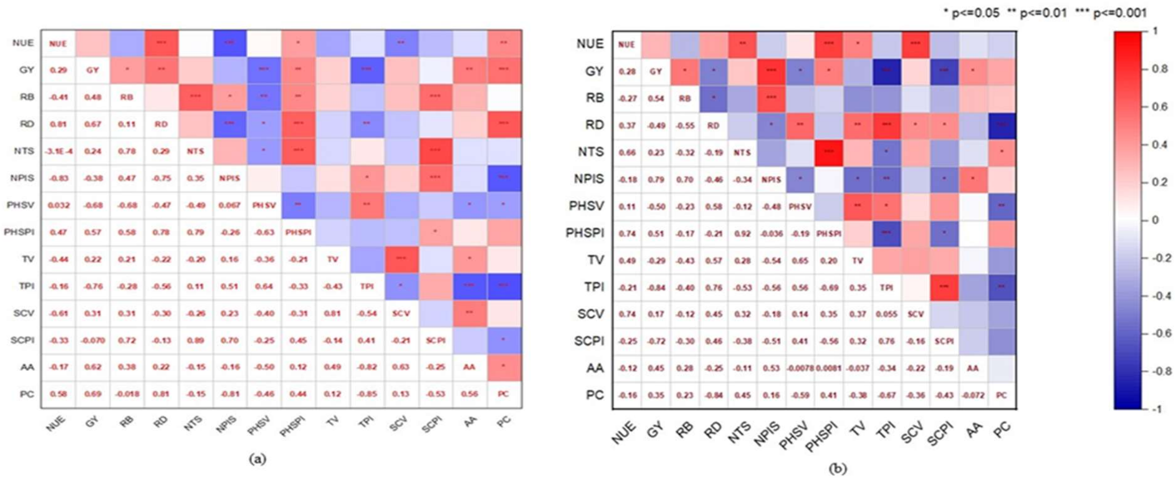

Figure 2: Correlation coefficient analysis of nitrogen use efficiency (NUE) and its contributing traits under (a) conventional management and (b) organic management

NUE - Nitrogen use efficiency, GY - Grain yield per hill, RB - Root biomass, RD - Root depth, NTS - Soil N at Tillering stage, NPIS - Soil N at panicle initiation stage, PHSV - Photosynthetic rate at vegetative stage, PHSPI - Photosynthetic rate at panicle initiation stage, TV - Transpiration rate at vegetative stage, TPI - Transpiration rate at panicle initiation stage, SCV - Stomatal conductance at vegetative stage, SCPI - Stomatal conductance at panicle initiation stage, AA – Amino acid content, PC - Protein content

Conclusion

The four rice varieties used in this study showed significantly better performance under conventional nutrient management in terms of growth, physiological, and yield parameters. Although the nitrogen use efficiency of each variety varied significantly with nutrient management practices, the variation was least in Jaiva (23.8%), which is the organic rice variety released by Kerala Agricultural University. The increased photosynthetic rate at the panicle initiation stage, transpiration rate, and stomatal conductance at the vegetative stage might have contributed to increased uptake of nitrogen, leading to increased NUE and productivity under organic management.

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Conflict of interest
The authors declare that they have no conflict of interest.

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